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QUALITATIVE CHANGES IN CARROT PRESERVES DEPENDING ON FOLIAR FERTILIZATION OF PLANTS WITH MAGNESIUM AND ON SELECTED TECHNOLOGICAL PROCESSES

S u m m a r y

Carrots cultivated in Poland are either sold as fresh vegetables or preserved. The quality of processed products does not depend only on the properly implemented technological process, but, also on the biological value of the initial raw material.

The objective of the research study was to determine the impact of foliar fertilization of plants with a 3 % solution of magnesium amounting to: 0, 45, and 90 kg of MgO ha^{-1} on the quality of roots of five carrot cultivars (‘Berio’, ‘Flacoro’, ‘Karotan’, ‘Koral’, and ‘Perfekcja’). Moreover, the effect of processing operations of carrot roots was determined as regards the quality of frozen and dried products as well as the quality of preserves in jars.

The highest amounts of total carotenoids and vitamin C were found in the products produced from storage roots of carrot cultivated on small fields that were fertilized with a magnesium dose of 90 kg ha^{-1}. Irrespective of the applied processing operation, there were reported losses of carotenoids: 36.1 %, of vitamin C: 59.2 %, and of magnesium: 23.3 %. Under the freezing and preserving processes, the losses of carotenoids and vitamin C were the lowest, whereas under the drying process, the losses of those two components were the highest. The levels of those losses were, respectively: 28.6 and 23.6 % in the frozen products; 27.7 and 64.4 % in the preserves, and 51.9 and 89.6 % in the dried products. As for magnesium, the losses reported were quite different to those of the two previous compounds: the highest losses of 52.3 % occurred under the preservation process, whereas the lowest of 0.14 % under the drying process. The preserves produced from roots of carrots fertilized by the highest dose of magnesium were characterized by the highest nutritional value. Of the investigated carrot cultivars, it was found that the order of suitability for processing was ‘Karotan’, ‘Koral’, and ‘Perfekcja’.

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Introduction

As a result of economical, social, and cultural processes in modern societies, consumer needs change dynamically and generate the demand for convenient, safe, and readily accessible food that enables easy preparation of meals [2, 6, 12, 23, 26, 38, 39]. Carrot, because of its constituents, is a plant of high nutritional value [11, 12, 18, 21, 33]. Thus, the demand for fresh carrots is high. In addition, the processing industry, where carrot is a very important raw material, applies high quantities of carrot. About 20 % of the total yield of carrots are industrially processed; therefore, this product is and will be one of the most important crops for food manufacturing purposes [7, 12, 21]. The processing of carrots comprises such technologies as freezing, preserving in jars, drying, and making juice. The quality of end-products also depends on whether or not the technological processes applied are appropriately performed [16]. The content of organic and mineral compounds, described as biological value [7, 21, 32, 33], determines, to a large extent, whether or not carrot roots are or are not suitable for processing. It is well known that the basic nutritional elements (N, P, K) contained in the roots of carrots decide the value thereof [30]. Moreover, the carrot requires soil rich in magnesium, because a yield of 100 t of carrots extracts 21 kg of magnesium from the soil, and 15 kg accounts for a marketable root yield [28]. Magnesium is involved in the metabolism of carbohydrates and in protein synthesis. It activates enzymatic reactions and represents a main component of chlorophyll. Therefore, research studies were conducted in order to determine the quality of products frozen, dried and preserved in jars, and produced from five carrot cultivars fertilized by foliar feeding with magnesium sulphate during the growing season.

Material and methods

The investigation material used in the research study came from 3-year lasting field experiments conducted at the Experimental Station in Mochełek, Faculty of Agriculture and Biotechnology of University of Science and Technology in Bydgoszcz. Those field experiments were carried out on a light sandy soil with a low content of magnesium, using a split-plot system, with three replicates. The experiments comprised the following factors: five cultivars (‘Berio’, ‘Flacoro’, ‘Karotan’, ‘Koral’, ‘Perfekcja’) and three magnesium doses (0, 45, and 90 kg MgO ha^{-1}) in the form of magnesium sulphate (‘EPSO Top’ include 16 % of MgO) and applied to the leaves at a concentration of 3 % during the phase of intensive plant growth. The basic needs of plants were covered by fertilizing the fields with 70 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1} and

100 kg K_2O ha^{-1} before planting. Agrotechnical treatments of plant protection against diseases and pests were performed in accordance with the needs of the carrot: the seeds were treated with Funaben T seed dressing, in every experiment year, and, as a pre-emergence herbicide, Stomp 330 EC was applied.

The carrots used for the preservation in jars and for freezing were cut into cubes 1cmx1cmx1cm, whereas the carrots for drying were sliced into 0.4 cm thick pieces. After cutting, the carrots water blanched at a temperature of 95 ºC during 3 minutes and immediately thereafter they were cooled down in water. The carrot preserves in jars were prepared according to the official Polish Standards PN–A-77807:1997/Az1:2004. Hot 'Twist' jars were filled to ¾ of their volume with the previously prepared carrot cubes. A salt solution (2 g NaCl per 1 litre of water) was added to the carrot cubes in the jars. The jars were sealed and pasteurized twice at preset temperatures ranging from 85 to 95 ºC for 30 min on two consecutive days. After the jars with carrots were cooled, they were stored in a dark, cool, and dry place. The products that has to be frozen were processed in a freezer (Whirlpool, CO405W with an electronic control system of a range between -1 and -30 ºC) at a temperature between –22 and –24 ºC. The drying process was conducted at a temperature of 60 ºC (for 24 h); then, for 1 hr at 105 ºC in a laboratory oven (WAMED, model SUP – 100, Poland) with an artificial air circulation. The dry matter was determined by weighing acc. to PN-EN 12145:2001. The ruling principle is that a sample is dried to a constant weight under certain pressure and temperature conditions and a percentage of the dry residue of the sample before drying is calculated. After carrot preservation, total carotenoids, ascorbic acid, and magnesium contents were determined, where total carotenoids and β-carotene were evaluated spectrophotometrically after PN-EN 12136:2000, ascorbic acid levels were measured spectrophotometrically after PN-A-04019:1998 (Shimadzu UV-1800, UV Spectrophotometer System, Japan), by the method, in which 2,6-dichlorophenolindophenol dye is reduced by ascorbic acid. The magnesium content was measured by atom absorption spectroscopy. The analyses were performed on material in three replications. The material was washed in a tap and in the distilled water, and, then, ground down. Next, it was dried until a constant weight was reached; initially at 60 °C, and then 105 °C. Dried potatoes (1.0 g of a sample) were ground and a mixture of H_2SO_4 (10 ml) and H_2O_2 (1 ml) was added. Then, the plant material was mineralised in a laboratory oven in a Digest Automat K-438 with an auto-Sampler K371 (Büchi, Switzerland) and, also, during one cycle (2 h). Following the filtration, the content of magnesium was determined using an AAS AA240FS Fast Sequential Atomic Absorption Spectrometer, manufactured by Varian (USA). The contents of magnesium are expressed as g kg^{-1} of dry matter.

A daily consumption rate of the bioactive compounds investigated was evaluated based on the assumed consumption rate of carrot products that equalled 55 g per capita (acc. To GUS 2001-2011). The results calculated were compared with the RDA amounts (RDA = Recommended Dietary Allowances). The vitamin A amounts were calculated by converting 18 mg of total carotenoids into 1 mg of retinol; those amounts were presented as retinol equivalents (RE).

The results from three experimental years were statistically analyzed using relevant tests to check the normal distribution of data and the homogeneity of their variances. Then, the resulting mean values were compared using a Two-Way ANOVA at a significance level of 0.05. The significant differences were identified by Tukey tests.

Results and discussion

Table 1 contains results that refer to the total carotenoids in frozen and dried products as well as to the preserves in jars, all of them produced from the five cultivars as indicated above. The highest significant content of carotenoids was reported in the ‘Perfekcja’ and ‘Karotan’ cultivars, whereas the lowest in the ‘Flacoro’ cultivar. Irrespective of the cultivars, the highest content of carotenoids was found in the carrots preserved in jars (mean value: 86.80 mg kg^{-1} of the product). Domaradzki et al. [7], while investigating the content of β-carotene in preserved carrot products, found higher amounts compared to the present results, viz. 198.9 mg kg^{-1} for carrots preserves in jars produced by “Bonduelle” Co. and 154.3 mg kg^{-1} for the carrots preserves in jars produced by “Jamar” Co. The above mentioned authors evaluated products from different markets; they had no information on the type of cultivars, the cultivation methods, and the processing technology. Wachowicz and Czarniecka-Skubina [33] reported that the amount of total carotenoids in carrot after cooking was at a level up to 127 – 136.6 mg kg^{-1} of the product. However, the investigations by Marx et al. [20] and by Chen et al. [5] showed the contents of carotenoids in pasteurized carrots between 52.7 and 134.2 mg kg^{-1}. Obviously, the differences between the results of the authors of this paper and those of others depend on the kind of carrot preserves, cultivar, and storage time.

In the above described experiments, the content of carotenoids in the frozen products was comparable to those in the thermally treated preserves and its level was 86.07 mg kg^{-1} on average. The highest concentration thereof was found in the frozen ‘Perfekcja’ and ‘Karotan’ carrots. This is possible because those two cultivars were characterized by a more intense colour compared to other cvs – a proof of a higher content of the carotenoids, which are, among other things, responsible for the colour of the carrot roots. Platta and Kolenda [24] performed an organoleptic evaluation of frozen carrots and they found statistically significant correlations between the cultivar and the visual appearance (especially colour). Frozen products made from ‘Napa F_1’ cv. were higher rated then those from ‘Nerrac F_1’ cv. Under the present research study, the ‘Napa F_1’ cv. was also higher rated (higher acceptance). Thus, it can be concluded that the differences between those two cultivars were caused by differences in the content of carotenoids therein.

Table 1. Content of carotenoids in processed carrot [mg kg^{-1} of product weight]
Tabela 1. Zawartość karotenoidów w marchwi przetworzonej [mg kg^{-1} masy produktu]

Cultivars / Odmiany [A]	Fertilization with MgO / Nawożenie MgO kg ha^{-1} [B]			LSD / NIR $_{p=0,05}$
	0	45	90	
Frozen products / Mrożonki				
Berjo	74,5 ± 13,8	79,7 ± 16,0	81,5 ± 18,2	A[1] = 17,32 B[1] = 1,71 B/A = n.s. / ins.[2] A/B = n.s./ ins.
Flacoro	71,2 ± 12,1	72,9 ± 13,0	76,0 ± 12,0	
Karotan	94,0 ± 20,8	100,1 ± 21,9	103,1 ± 22,9	
Koral	75,2 ± 8,0	78,4 ± 6,2	84,1 ± 10,9	
Perfekcja	95,5 ± 20,1	101,6 ± 23,5	103,1 ± 24,5	
$\bar{x}$	82,1 ± 17,1	86,5 ± 19,1	89,6 ± 19,6	
Dried products / Susze				
Berjo	59,3 ± 0,6	60,3 ± 7,5	62,7 ± 11,9	A = 6,09 B = 0,56 B/A = 1,25 A/B = 6,21
Flacoro	52,6 ± 45,3	50,9 ± 44,0	49,3 ± 44,6	
Karotan	64,8 ± 48,2	62,9 ± 47,7	63,3 ± 61,1	
Koral	45,9 ± 58,2	46,2 ± 48,3	47,9 ± 66,1	
Perfekcja	66,6 ± 55,3	68,1 ± 58,5	67,3 ± 59,4	
$\bar{x}$	57,9 ± 93,5	57,7 ± 68,7	58,1 ± 62,3	
Preserves in jars / Konserwy w słoikach				
Berjo	78,7 ± 7,7	85,0 ± 8,0	86,7 ± 9,7	A = 12,57 B = 0,89 A/B =12,71 B/A = 1,99
Flacoro	75,0 ± 7,0	77,3 ± 6,8	80,4 ± 5,9	
Karotan	94,0 ± 12,3	98,1 ± 13,9	101,1 ± 14,9	
Koral	79,5 ± 4,5	80,9 ± 3,4	82,5 ± 3,5	
Perfekcja	89,3 ± 13,1	96,0 ± 13,7	97,6 ± 15,1	
$\bar{x}$	83,3 ± 10,9	87,5 ± 12,0	89,7 ± 12,5	

Explanatory notes: / Objaśnienia:
Table 1 shows mean values from 3 experimental years ± standard deviations. / W tabeli przedstawiono wartości średnie z 3 lat badań ± odchylenia standardowe; n = 12; 1 – Tukey test / Test Tukey; LSD / NIR (p = 0,05) A (Cultivars / Odmiany), B (Fertilization with MgO / Nawożenie MgO); 2 – difference among mean values is statistically insignificant (ins.) ($p < 0.05$) / różnica między wartościami średnimi jest statystycznie nieistotna (n.i.).

The content of β-carotene in dried products was the smallest and amounted to 57.90 mg kg^{-1} on average. Similar to the case of preserves in jars and frozen products, the highest contents of carotenoids were found in the ‘Karotan’ and ‘Perfekcja’ cultivars. Also, their fresh mass had the highest content of carotenoids. According to [10, 15, 29], carotenoids are considered to be thermostable pigments. The doses of magnesium applied while growing carrots significantly increased the contents of carotenoids in all the products investigated (Tab. 1). Where a 90 kg MgO ha^{-1} dose was applied, the highest contents of carotenoids were determined in the preserves in jars and in the frozen carrots, and the smallest content – in the dried products. Compared to the combination without additional nutrition with magnesium, the increase in the content of carotenoids was, respectively: 8.3 % in the frozen products, 7.1 % in the preserves in jars, and 0.4 % in the dried carrots.

From the nutritional point of view, the content of ascorbic acid is very important for it influences antioxidative mechanisms in human body. Carrot is the main source of ascorbic acid in the diet of Polish citizens [7], after potatoes, tomatoes, and white cabbage. According to [7], depending on cultivar, the content of ascorbic acid in 1 kg of fresh mass of carrot roots is 6-10 mg [21], 5.9 mg [14], 6.0 mg [34], and 6.52-9.78 mg [19]. In addition, those authors reported, in line with Alasalvar et al. [1], that the storage roots of more colour-intensive cultivars were characterized by higher contents of ascorbic acid.

Table 2. Content of ascorbic acid in processed carrot – mean values from 3 experimental years [mg kg^{-1} product weight]

Tabela 2. Zawartość kwasu askorbinowego w marchwi przetworzonej – średnio z 3 lat badań [mg kg^{-1} masy produktu]

Cultivars / Odmiany [A]	Fertilization with MgO/ Nawożenie MgO kg ha^{-1} [B]			LSD / NIR $_{p=0,05}$
	0	45	90	
Frozen products / Mrożonki				
Berjo	5,85 ± 0,4	6,08 ± 0,3	6,65 ± 0,7	A[1] = n.s. / n.i.[2] B[1] = 0,19 B/A = n.s. / n.i. A/B = n.s. / n.i.
Flacoro	6,12 ± 0,6	6,36 ± 0,8	6,85 ± 0,4	
Karotan	7,50 ± 2,1	8,29 ± 2,3	8,72 ± 2,6	
Koral	7,73 ± 2,1	8,20 ± 2,1	8,54 ± 2,2	
Perfekcja	7,72 ± 1,8	8,32 ± 2,3	8,58 ± 2,3	
$\bar{x}$	6,98 ± 1,6	7,45 ± 1,8	7,87 ± 1,8	
Dried products / Susze				
Berjo	0,90 ± 0,04	0,98 ± 0,08	1,10 ± 0,03	A = n.s. / n.i. B = 0,02 B/A = 0,05 A/B = 0,07
Flacoro	0,87 ± 0,03	1,01 ± 0,02	1,10 ± 0,03	
Karotan	0,96 ± 0,03	1,03 ± 0,01	1,08 ± 0,05	
Koral	0,96 ± 0,02	1,02 ± 0,01	1,06 ± 0,02	
Perfekcja	0,96 ± 0,01	1,04 ± 0,04	1,07 ± 0,01	
$\bar{x}$	0,93 ± 0,04	1,02 ± 0,04	1,08 ± 0,03	
Preserved in jars / Konserwy w słoikach				
Berjo	2,99 ± 0,15	3,37 ± 0,06	3,97 ± 0,50	A = 0,47 B = 0,18 B/A = n.s. / n.i. A/B = n.s./ n.i.
Flacoro	2,97 ± 0,27	3,20 ± 0,10	3,49 ± 0,09	
Karotan	2,90 ± 0,40	3,52 ± 0,12	3,85 ± 0,09	
Koral	3,49 ± 0,18	3,73 ± 0,07	4,19 ± 0,19	
Perfekcja	3,24 ± 0,27	3,36 ± 0,38	3,58 ± 0,49	
$\bar{x}$	3,12 ± 0,32	3,44 ± 0,24	3,82 ± 0,38	

Explanatory notes as in Tab. 1. / Objaśnienia jak pod Tab. 1.

In the presented research study, the differences in the contents of ascorbic acid between the tested cultivars, processed to produce frozen or dried products, were not found (Tab. 2). Only in the case of carrot preserves in jars, the cultivars significantly varied in their ascorbic acid content; its highest mean value equalling 3.8 mg kg^{-1} was determined in ‘Koral’.

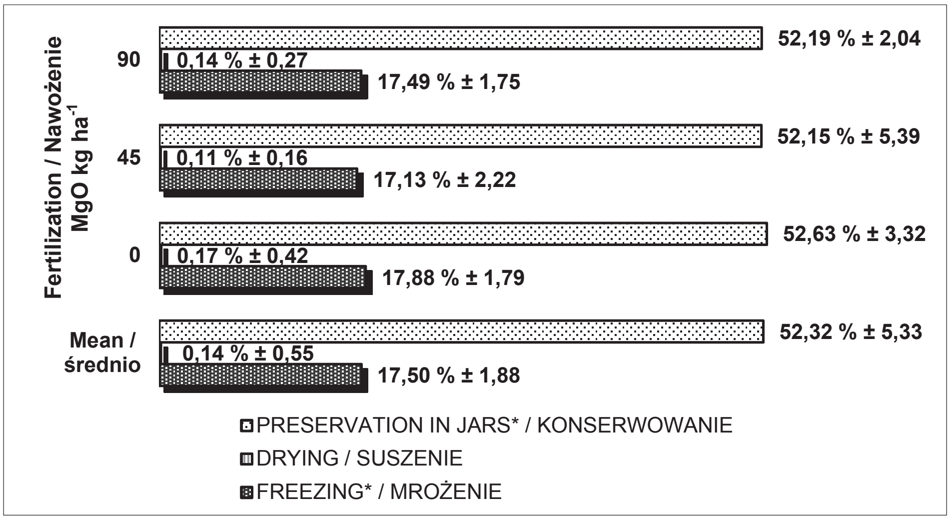
Irrespective of the cultivar, the highest content of ascorbic acid was determined in the frozen products (7.43 mg kg^{-1}, Tab. 2). These results differ from those of Polak et al. [26] who reported 2.1 mg ascorbic acid kg^{-1} of the product for frozen carrots. The positive influence of magnesium nutrition on ascorbic acid content in the frozen and dried products, and in the preserves in jars was statistically significant (Tab. 2). The highest increase in ascorbic acid was found, as in the case of carotenoids, in the products from carrots supplied with the highest magnesium dose of 90 kg MgO ha^{-1}. Compared to the control sample, the increase was 12.7 % in the frozen products, 15.1 % in the dried products, and 22.4 % in the carrot preserves in jars. In contrast to the present results, Biesiada et al. [3] did not report any significant influence of leaf nutrition with macro- and microelements on the content of ascorbic acid in fresh carrots, although those carrots were not processed.

Table 3. Content of magnesium in processed carrot – mean values from 3 experimental years [g kg^{-1} of d.m.]
Tabela 3. Zawartość magnezu w marchwi przetworzonej – średnie z 3 lat badań [g kg^{-1} s.m.]

Cultivars / Odmiany [A]	Fertilization with MgO/ Nawożenie MgO kg ha^{-1} [B]			LSD / NIR $_{p=0,05}$
	0	45	90	
Frozen products / Mrożonki				
Berjo	1,71 ± 0,03	1,81 ± 0,18	1,96 ± 0,12	A^1 = 0,03 B^1 = 0,02 B/A = 0,04 A/B = 0,05
Flacoro	1,50 ± 0,10	1,75 ± 0,20	1,87 ± 0,04	
Karotan	1,51 ± 0,01	1,66 ± 0,06	1,96 ± 0,09	
Koral	1,43 ± 0,46	1,78 ± 0,13	2,01 ± 0,22	
Perfekcja	1,72 ± 0,04	1,73 ± 0,19	2,09 ± 0,09	
$\bar{x}$	1,57 ± 0,21	1,75 ± 0,14	1,98 ± 0,13	
Dried products/ Susze				
Berjo	0,90 ± 0,04	0,98 ± 0,08	1,10 ± 0,03	A = 0,04 B = 0,03 B/A = 0,07 A/B = 0,08
Flacoro	0,87 ± 0,03	1,01 ± 0,02	1,10 ± 0,03	
Karotan	0,96 ± 0,03	1,03 ± 0,01	1,08 ± 0,05	
Koral	0,96 ± 0,02	1,02 ± 0,01	1,06 ± 0,02	
Perfekcja	0,96 ± 0,01	1,04 ± 0,04	1,07 ± 0,01	
$\bar{x}$	0,93 ± 0,04	1,02 ± 0,04	1,08 ± 0,03	
Preserves in jars / Konserwy w słoikach				
Berjo	1,69 ± 0,02	1,79 ± 0,11	1,95 ± 0,20	A = 0,06 B = 0,04 B/A = 0,09 A/B = 0,11
Flacoro	1,49 ± 0,08	1,73 ± 0,12	1,86 ± 0,06	
Karotan	1,50 ± 0,07	1,65 ± 0,04	1,94 ± 0,11	
Koral	1,41 ± 0,24	1,77 ± 0,12	2,00 ± 0,23	
Perfekcja	1,70 ± 0,09	1,72 ± 0,16	2,08 ± 0,06	
$\bar{x}$	1,56 ± 0,14	1,73 ± 0,12	1,97 ± 0,16	

Explanatory notes as in Tab. 1. / Objaśnienia jak pod Tab. 1.

The analysis of variance did not show any significant differences in the content of magnesium between the investigated cultivars in each of the considered products (Tab. 3). Irrespective of the processing technology, the content of magnesium ranged from 1.68 to 1.87 g kg^{-1} of dry matter.



LSD / $NIR_{p=0,05}$ A (fertilization with MgO/ nawożenie MgO) – 1,10; B – (processing method / sposób przetwarzania) 1,03; A/B – 1,81; B/A – 1,78

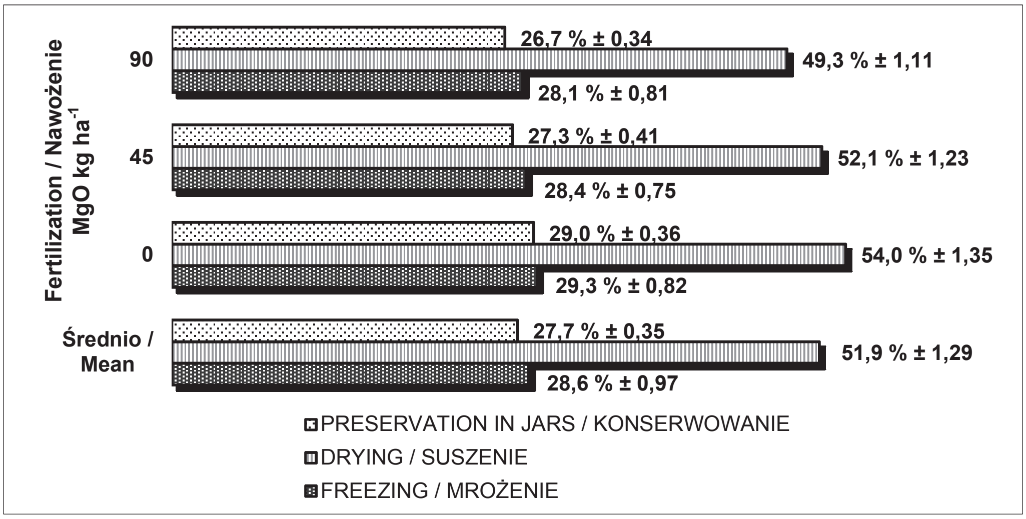
* - losses of Mg were calculated based on dry matter in processed products / wyliczono straty magnezu uwzględniając zawartość suchej masy w produktach przetworzonych

Fig. 1. Losses [%] of magnesium in storage roots of carrots depending on leaf fertilization with MgO and processing technology – mean values for individual cultivar and year of experiments

Rys. 1. Straty [%] magnezu w korzeniach spichrzowych marchwi w zależności od nawożenia MgO i technologii przetwarzania – średnio dla odmian i lata badań

For comparison, Majkowska-Gadomska and Wierzbicka [19] as well as Platta and Kolenda [25] reported, respectively, the contents of 1.0 to 1.2 and 2.8-3.2 g kg^{-1} of dry matter in the cultivars other than the ones used here. The applied magnesium nutrition significantly influenced the content of this nutrient in the processed products, where the positive dependency was linear (Tab. 3): a higher magnesium dose resulted in a higher content of magnesium in the product. With a dose of 90 kg ha^{-1}, the concentration of magnesium in the investigated products was 1.77 g kg^{-1} of dry matter on average.

Furthermore, the additional magnesium fertilization had no effect on the extent of Mg^{+2} losses during processing (Fig. 1). As expected, the highest losses were detected in the case of carrot preservation (52.32 %) and followed by freezing of the carrots (17.50 %) and by drying them (0.14 %) owing to leaching processes.



LSD / NIR $_{p=0,05}$ A (fertilization with MgO/ nawożenie MgO) – 10.85; B (processing method / sposób przetwarzania) – 1,18; A/B – n.s.[1] / ins.; B/A –n.s. / ins.
[1] - insignificant difference / nieistotna różnica

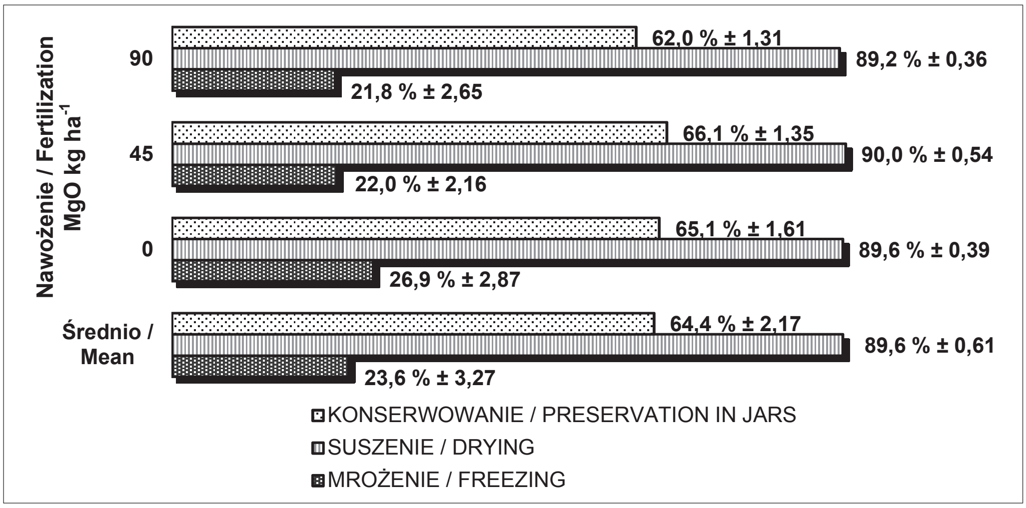
Fig. 2. Losses [%] of total carotenoids in storage roots of carrots depending on leaf fertilization with MgO and processing technology – mean values for individual cultivars and year of experiments
Rys. 2. Straty [%] sumy karotenoidów w korzeniach spichrzowych marchwi w zależności od nawożenia MgO i technologii przetwarzania – średnio dla odmian i lat badań

Technological operations such as peeling, washing, size reduction, cooking, blanching, or thawing may cause losses in the product compounds. In the case of drying, freezing, or preserving in jars, where other factors interact in combination with the thermal preserving process, the risk of losing chemical compounds may be significant.

According to Buggenhout et al. [4], in all cases, the freezing stress causes the loss of quality in the frozen products. However, in comparison with other processing methods, this process is the best for maintaining the high quality of a product [9, 12, 13, 17, 26].

Only the freezing process results in small losses of carotenoids in a product. However, it is worth noting that before freezing, plant products should be pre-processed; in the case of carrots, they should be blanched. The blanching process causes the highest losses of carotenoids pigments; Fik et al. [9] report about 17 % in their investigations; Gębczyński [12]: 6 %, and Kozłowska-Wojciechowska [17]: 20 to 30 %. The results as presented under this study (Fig. 2) were in line with the cited reference literature because, irrespective of the cultivar, the losses of carotenoids were determined in the frozen products. However, with 28.6 % on average, the present losses were higher than those mentioned in the reference literature. It should be stressed that those losses were found in the frozen products, which underwent various pre-processing operations. According to Gębczyński [12], the contents of total carotenoids and β-carotene in the frozen carrots could be very high up to the level of 37 % of total carotenoids and 24 % of β-carotene; the values indicated referred to the products stored for a period of 12 months. The above author pointed out that the nutritional value of frozen carrots is also influenced by the storage temperature. A decrease in the storage temperature by 10 °C from -20 °C to -30 °C limited the losses of the compounds investigated by 7 to 12 %. The application of magnesium fertilization did not considerably influence the losses of carotenoids in the frozen products (Fig. 2), which were 28.6 % on average. Freezing plus such processes as washing of raw materials, spraying, cooling, and blanching during pre-processing are an important cause of losses of ascorbic acid. Those losses could be explained by a high water-solubility of this vitamin and its susceptibility to oxidation. According to Kozłowska-Wojciechowska [17], the losses of ascorbic acid caused by the freezing process itself were not higher than 20 %. Gayathri et al. [11], while investigating the levels of ascorbic acid and β-carotene in vacuum and conventionally cooled carrots, did not determine significant differences in the contents of those compounds. Zhang and Sun [39] reported that water spraying applied in addition to the cooling process reduced, even more, the losses of quality compounds in carrots. However, Gołaszewska and Czarniecka-Skubina [13] stated that, as a consequence of blanching, the losses could be even 60 %. Further investigations confirmed the latter results [31]. The above authors mentioned that the losses of this vitamin in the frozen and not blanched vegetables ranged from 20 to 30 % while in the case of the blanched vegetables, they were even 50 %. Gębczyński [12], while investigating carrots subjected to blanching and cooking prior to freezing, reported the losses of ascorbic acid between 40 % and 51 %, respectively. In the present research experiment, the losses, expressed as a percentage of ascorbic acid, were smaller in the frozen products: 23.6 % on average as regards the cultivars tested (Fig. 3). The differences could be explained by the elevated temperature during thawing and microwave radiation applied by the above mentioned authors. In the investigations by Gębczyński [12], the extension of the storage time and, at the same, the reduction of the temperature to -30 °C caused the losses of ascorbic acid and carotenoids to decrease (by ca. 7 % and ca. 8 %, respectively). In the present experiment, the application of 90 kg ha^{-1} of magnesium significantly reduced the losses of ascorbic acid in the frozen carrots (Fig. 3).

During the drying process, visual changes of carotenoids are caused by strong and long lasting oxidation [8, 35]. According to Świderski and Waszkiewicz-Robak [31], the losses of β-carotene during the drying process may be up to 20 %. However, other authors mentioned that the losses of carotene were not higher than 50 % [27]. The same authors determined a decrease in the content of carotenoids in their experiments with the conventionally dried and freeze-dried carrots, which was ca. 50% and 5%, respectively. Witrowa-Rajchert [35] dried carrots using fluidization and a ‘through the layer' and 'along the layer' methods; she reported a decrease in the carotenoids of 56 %, 26 %, and 16 %, respectively. In the present investigation, the drying process of the carrots resulted in high losses of carotenoids; they were 51.9 % on average (Fig. 2). The additional magnesium fertilization, applied during the vegetation period, limited those losses. The dried products of carrot fertilized with the highest amount of magnesium (90 kg ha^{-1}) were characterized by the lowest losses of carotenoids (49.3 %).



LSD / NIR $_{p=0,05}$ A (fertilization with MgO / nawożenie MgO) – 4,64; B (sposób przetwarzania / processing method) – 1,65; A/B – n.s.[1] / n.i. /; B/A – n.s. / ins.
* - insignificant difference / nieistotna różnica

Fig. 3. Losses [%] of ascorbic acid in storage roots of carrot depending on leaf fertilization with MgO and processing technology – mean values for individual cultivars and year of experiments.

Rys. 3. Straty [%] kwasu askorbinowego w korzeniach spichrzowych marchwi w zależności od nawożenia MgO i technologii przetwarzania – średnio dla odmian i lat badań.

According to Świderski and Waszkiewicz-Robak [31], the mean losses of ascorbic acid in the dried products were about 80 %. In the present experiment, the losses were higher: 89.6 % (Fig. 2). However, the additional application of magnesium fertilization lowered them.

One of the traditional methods to extend shelf-life of raw materials is food preservation through applying cooking salt solutions and high temperature (tin or jar production). Similar to the drying process, several changes in chemical contents occur also during the thermal processing of raw materials. Carrots were preserved according to the Polish standards: PN–A-77807:1997/Az1:2004. The peeled carrots, cut or whole, were covered with a cooking salt solution and preserved by sterilization. The changes that might occur during the sterilization process are correlated with the product consistency such as excessive softening, which considerably decreases the quality [13]. The authors [13] reported that the preservation process itself resulted in the decomposition of carotenoids between 2 and 4 %. In the present study, irrespective of the cultivars and fertilization level, the losses of carotenoids were 27.7% on average (Fig. 2). Those higher values were probably owing to the additionally applied blanching process. In the case of preserves in jars, the application of magnesium had no influence on the level of carotenoids during processing.

Under the present investigations, the degradation of ascorbic acid of sterilized carrots was 64.4 % on average (Fig. 3) and was in line with the reference literature [13, 22, 29]. The authors as named in [13] of the reference literature mentioned that, compared to the raw material, the losses of ascorbic acid in the preserved carrots might be up to 60% Several authors [29, 36, 37] referred to the fact that the ascorbic acid was thermo-labile. Consequently, high temperatures used during the preservation processes (tin or jar production) caused considerable losses. Since the ascorbic acid is highly water-soluble and susceptible to oxidation, it may decompose during pre-processing operations such as washing, cutting, or blanching [13]. According to Nowacka et al. [22], the storing of the preserved products also contributes to the losses of ascorbic acid. A 90 kg MgO ha^{-1} dose of the fertilizer applied reduced the losses compared to the products in jars produced from carrots with no leaf fertilization.

Table 4. Meeting daily nutritional needs of humans while consuming 55 g portion of carrot*: mean values for individual cultivars and year of experiments. [%]

Tabela 4. Pokrycie dziennego zapotrzebowania organizmu człowieka przy konsumpcji 55 g marchwi* – średnio dla odmian i lat badań. [%]

Dose / Dawka MgO kg ha^{-1}	Carotenoids Karotenoidy			Ascorbic acid Kwas askorbinowy			Magnesium Magnez		
	1	2	3	1	2	3	1	2	3
0	27,9	19,7	28,3	0,42	0,05	0,19	2,6	3,2	5,3
45	29,4	19,6	29,7	0,46	0,07	0,21	3,0	3,6	6,1
90	30,4	19,7	30,4	0,48	0,07	0,23	3,5	4,2	7,1

Explanatory notes: / Objaśnienia:
* - mean consumption level of fresh and processed carrot (without juices) is 20 kg $year^{-1}$ per person in Poland / średnie spożycie marchwi świeżej i przetworzonej (bez soków) wynosi 20 kg rok^{-1} przez osobę w Polsce
1 – frozen carrot / marchew mrożona; 2 – dried carrot / marchew suszona; 3 – carrot preserves in jars / marchew konserwowa; RDA (Recommended Dietary Allowances per day / Dzienne zapotrzebowanie organizmu – 100 %):Vitamin A / Witamina A – 900 µg day^{-1} / µg $dzień^{-1}$, (18 mg of carotenoids/ karotenoidy = 1 mg of vitamin A/ witamina A); Ascorbic acid / Kwas askorbinowy – 90 mg day^{-1} / mg $dzień^{-1}$; Magnesium / Magnez – 350 mg day^{-1} / mg $dzień^{-1}$.

At least 500 g of vegetables should be consumed per day in 4 to 5 portions. Carrot is the most often consumed vegetable, both fresh and processed; thus, a model estimation of a daily portion of consumed carotenoids, ascorbic acids, and magnesium was performed based on the assumed 55 g intake per capita and per day (Tab. 4). Comparing the results obtained with the RDA-based standards proved that when consuming a 55 g portion of the processed carrots investigated, the daily needs for ascorbic acid and magnesium were covered by these products to a very low extend (an average of 0.25 and 4.3 %). Wszelaczyńska and Pobereżny [37] also confirmed this dependence in relation to the roots of fresh carrots. However, in the case of carotenoids, the amounts are high. When computing the transformation of total carotenoids to retinol based on the assumption that 18 mg of carotenoids yielded 1 mg of retinol equivalent (RE), the daily demand for vitamin A was covered, on average, by 29.4 %, provided that 55 g of the preserves or frozen carrots were consumed. In the case of dried carrots this value was lower and amounted to 19.7 %.

Conclusions

1. The 'Karotan', 'Koral', and 'Perfekcja' cultivars were most suitable when processing carrots to produce frozen, dried, and sterilized products.
2. The fertilization of plants with magnesium increased the content of carotenoids and ascorbic acid in fresh carrots. The same was also confirmed in the case of the processed products (frozen and dried products as well as preserves in jars).
3. The freezing process caused the lowest losses of carotenoids and ascorbic acid, whereas the drying process generated the largest losses of those compounds.
4. A dose of 90 kg MgO ha^{-1} in the form of magnesium sulphate applied as an additional leaf fertilization during the vegetation period was confirmed to be the most appropriate for the processed products.

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ZMIANY JAKOŚCIOWE PRZETWORÓW Z MARCHWI W ZALEŻNOŚCI OD DOLISTNEGO NAWOŻENIA ROŚLIN MAGNEZEM ORAZ WYBRANYCH PROCESÓW TECHNOLOGICZNYCH

Streszczenie

Marchew uprawiana w Polsce przeznaczana jest do sprzedaży w postaci świeżego warzywa oraz do przetwórstwa. Jakość produktów przetworzonych zależy nie tylko od prawidłowo przeprowadzonego procesu technologicznego, ale również od wartości biologicznej surowca wyjściowego.

Celem pracy było określenie wpływu dolistnego nawożenia roślin 3-procentowym roztworem magnezu, w ilości 0, 45, 90 kg MgO ha^{-1}, na jakość korzeni pięciu odmianach marchwi (‘Berio’, ‘Flacoro’, ‘Karotan’, ‘Koral’, ‘Perfekcja’). Ponadto określono wpływ procesów przetwórczych korzeni na jakość mrożonek, suszu i konserw w słoikach.

Największą zawartość sumy karotenoidów i witaminy C uzyskano w przetworach wyprodukowanych z korzeni spichrzowych marchwi pochodzących z poletek nawożonych dawką magnezu 90 kg ha^{-1}. Niezależnie od zastosowanego procesu przetwarzania następowały straty karotenoidów średnio o 36,1 %, witaminy C – o 59,2 % a magnezu – o 23,3 %. Najmniejsze straty karotenoidów i witaminy C powodowały procesy mrożenia i konserwowania, największe – proces suszenia. Straty te wynosiły odpowiednio: 28,6 % i 23,6 % w mrożonkach, 27,7 % i 64,4 % – w konserwach oraz 51,9 % i 89,6 % – w suszu. Odwrotne wyniki uzyskano w przypadku magnezu, którego największe straty powodował proces konserwowania – 52,3 %, a najmniejsze suszenia – 0,14 %. Największą wartością odżywczą charakteryzowały przetwory wyprodukowane z korzeni marchwi nawożonych najwyższą dawką magnezu. Z badanych odmian marchwi do przetwórstwa najbardziej przydatne okazały się kolejno: ‘Karotan’, ‘Koral’ i ‘Perfekcja’.

Słowa kluczowe: marchew, odżywianie roślin, magnez, mrożenie, suszenie, konserwowanie w słoikach, karotenoidy, kwas askorbinowy